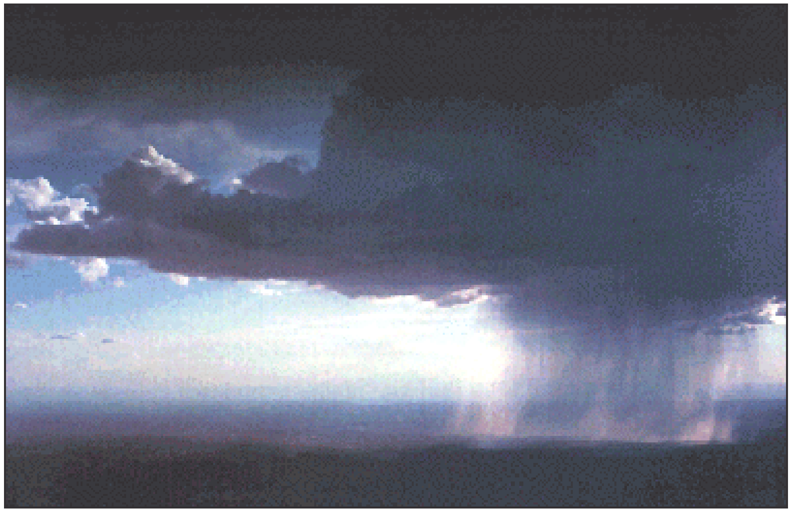
GPM



GPM

Global Precipitation Measurement

JPL Planned Contribution to GPM

Eastwood Im, Ziad S. Haddad
JPL
5/16/2001

Introduction

- JPL planned contribution:
  - Develop radar technologies which have potential to reduce radar mass and/or improve radar data quality
  - Conduct field experiment and acquire data with the new dual-frequency (14/35-GHz) airborne rain radar for supporting GPM radar algorithm development and cal/val planning
  - Perform radar observation and instrument design trade study
  - Provide preliminary assessment of GPM precipitation radar-only and radar/radiometer combined algorithms
  - Support the study of various mission architecture and design options

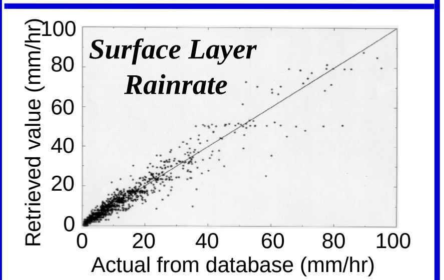
1: Develop Spaceborne Precipitation Radar Technologies

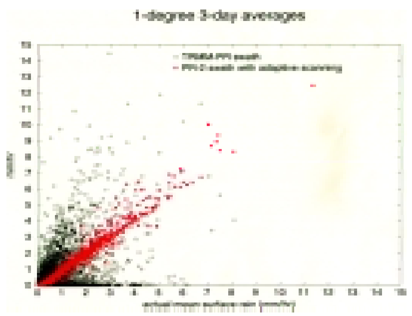
- Through the NASA Earth Science Technology Program, JPL has been developing advanced spaceborne rain radar technologies to support future spaceborne rain missions, such as Global Precipitation Mission (GPM)
- Accomplishments:
  - Prototyped the electronics subsystem for an integrated 14/35 GHz radar
    - Developed a real-time on-board rain data processor based on FPGA technology that performs 20 billion multiplications and 20 billion additions per second, a throughput equivalent to about 20 PCs working in parallel
    - Developed a highly compact, light-weight, dual-frequency, dual-polarization RF and digital subsystems based on VME architecture. These subsystems occupy only 6 slots in a standard VME card cage
  - Built a scanning dual-frequency reflector antenna to support the airborne operation of the electronics prototype
  - Developed an efficient adaptive scan algorithm for real-time identification of rain cell locations
  - Developed a conceptual design of a light-weight, wide-swath scanning, 5.3-m deployable antenna
    - Cross-track adaptive scan over ±37˚ to increase swath coverage
    - 2-km horizontal resolution at 450 km
    - ~100 kg

Advanced Precipitation Radar Technologies

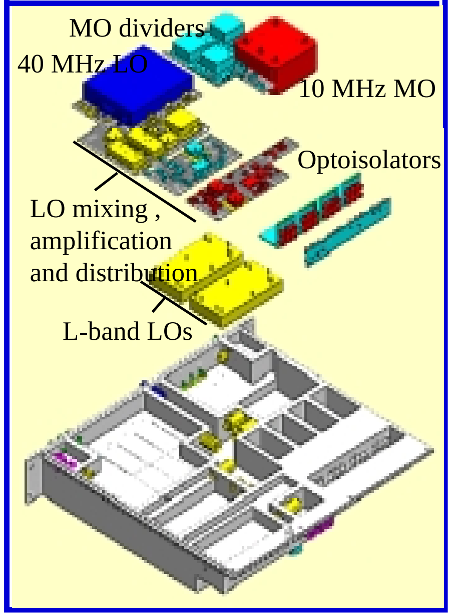
Task 1: Develop instrument design and prototype critical rain radar hardware for airborne demonstration

Algorithm and System Studies

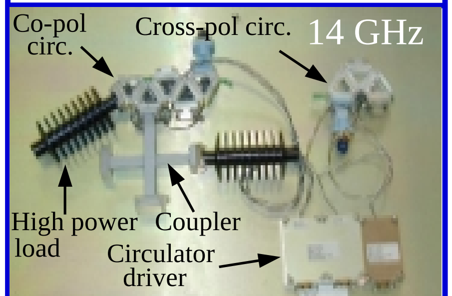


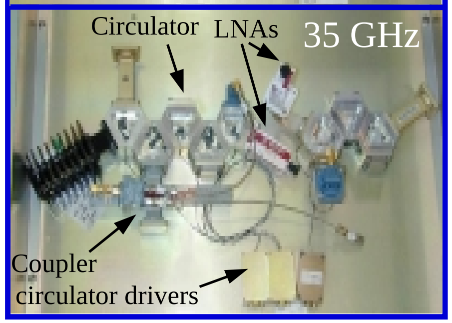


RF Electronics Subsystem

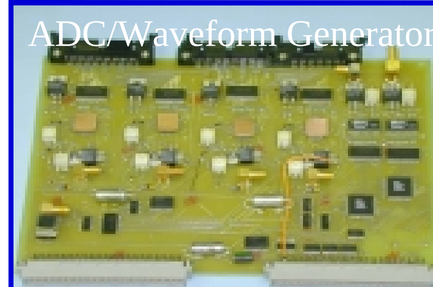


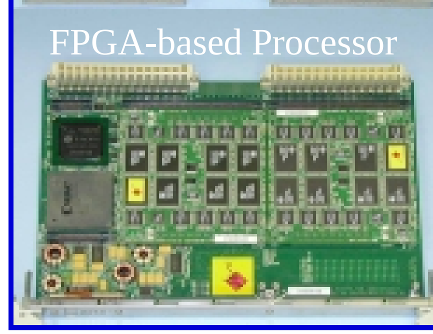
RF Components (Airborne)



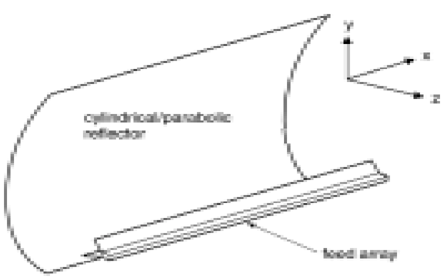


Digital Electronics Subsystem

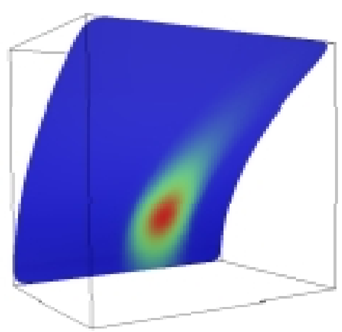




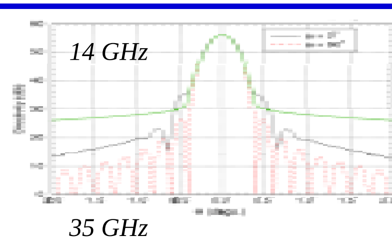
Task 2: Develop a design for a light-weight, dual-frequency spaceborne precipitation radar antenna



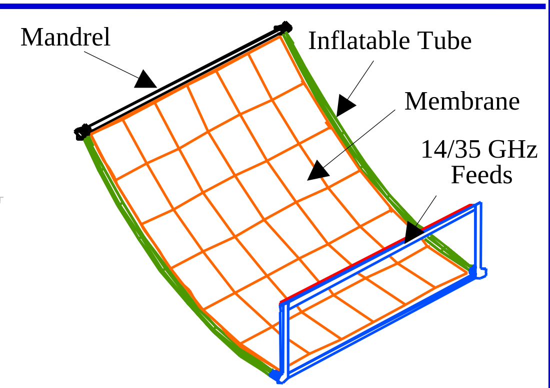
14/35-GHz Antenna Design



Full & Under-Illumination to get Matched Beams



Antenna Patterns at 0Þ S



Inflatable Antenna Structure

2: Airborne Precipitation Radar Experiments

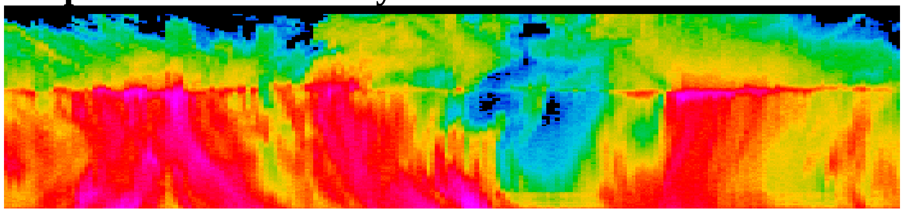
- The Airborne Rain Mapping Radar (ARMAR) was developed in early 1990's
  - Operated on DC-8 with TRMM PR geometry and frequency
  - also provides dual-polarization and Doppler capabilities
  - Field experiments with ARMAR
    - TOGA-COARE (1993)
    - TEFLUN-B / CAMEX3 (1998)
    - KWAJEX (1999)

- The new dual-frequency airborne rain radar will participate in CAMEX-4 experiment (8-9 / 2001)
  - Will operate on DC-8 with the planned GPM radar geometry and frequency
  - Will support GPM radar algorithm development and calibration / validation planning

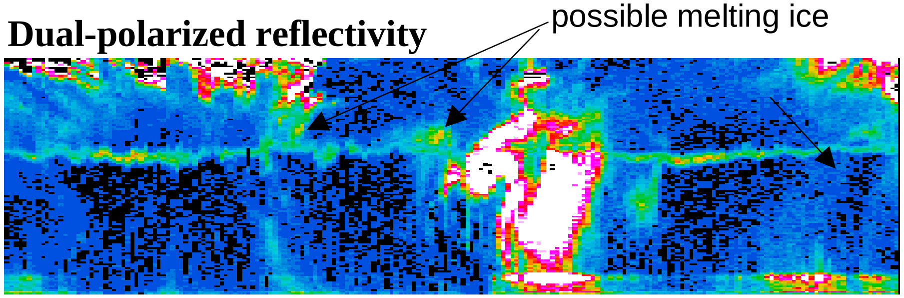
- Current status
  - The radar ground testing will be completed in May'01
  - Airborne engineering flights (20 hours) are scheduled for June'01

Examples of ARMAR Measurements and Science Results

Co-polarized reflectivity



Dual-polarized reflectivity

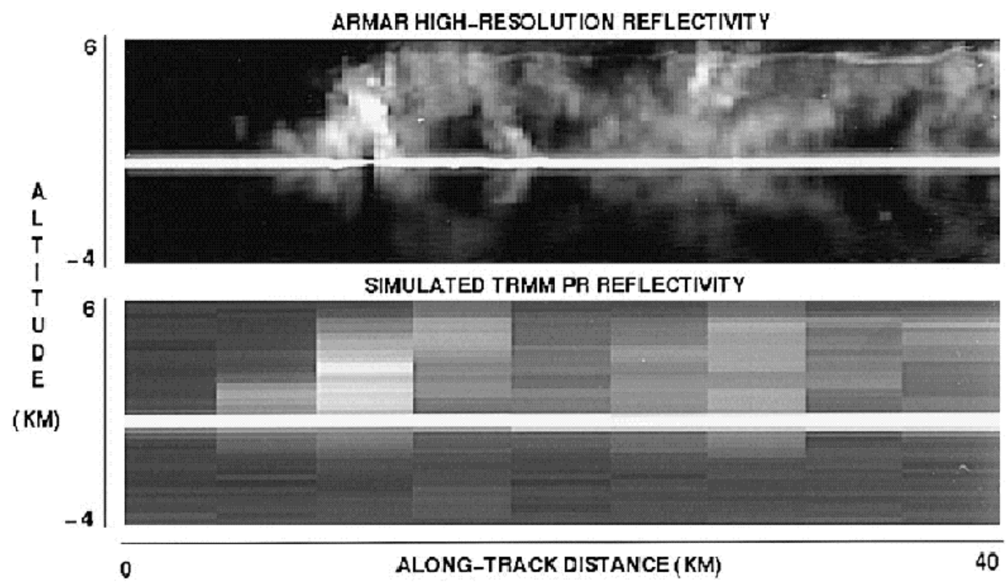


- TRMM PR makes co-polarized measurements so some assumptions about location of melting ice are made in retrieving rain.
- ARMAR's dual-polarization measurements can be used to validate assumptions.
- ARMAR on the NASA DC-8 observed Hurricane Bonnie near North Carolina during CAMEX-3
- Lower panel is dual-polarization data, showing areas of possible melting ice.

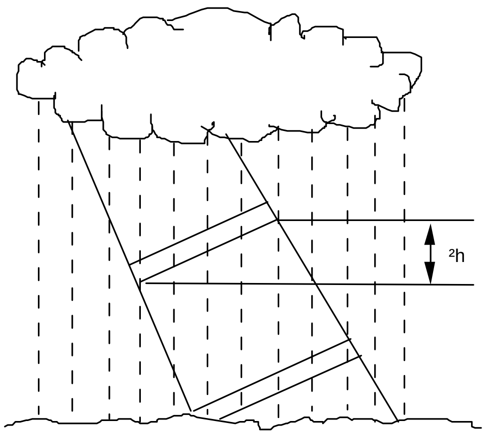
Vertical axis is altitude above ocean; horizontal axis is distance along aircraft track. Hurricane eye is blue area to right of center in upper image, corresponding white area in lower image.

Non-Uniform Beamfilling Studies

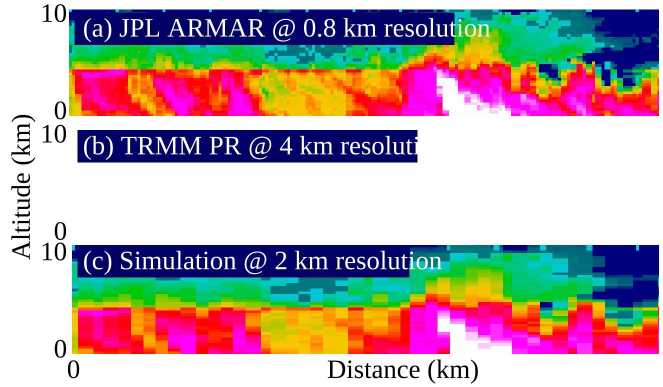
- ARMAR's high resolution allowed effects of TRMM PR's 4 km resolution to be studied:
  - retrieve rain profile from ARMAR data and average to PR resolution
  - average ARMAR reflectivity to TRMM resolution and then retrieve rain
  - compare results over all TOGA COARE data to derive error statistics
  - Results in Durden et al., 1998, JTECH.



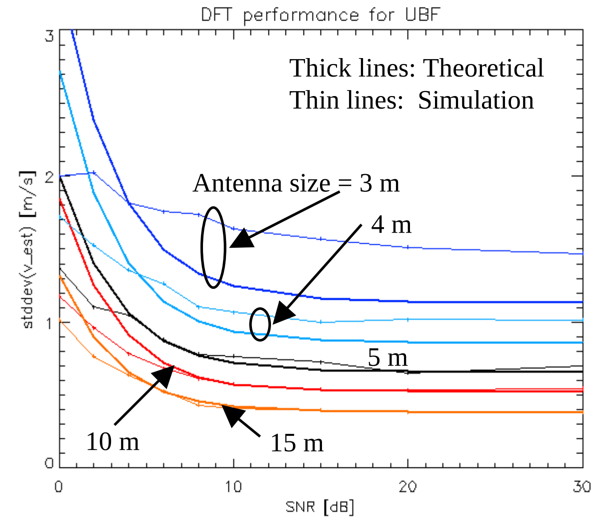
3: Radar Design Trade Studies



Antenna size vs.
surface clutter interference



Horizontal resolution vs.
non-uniform beamfilling

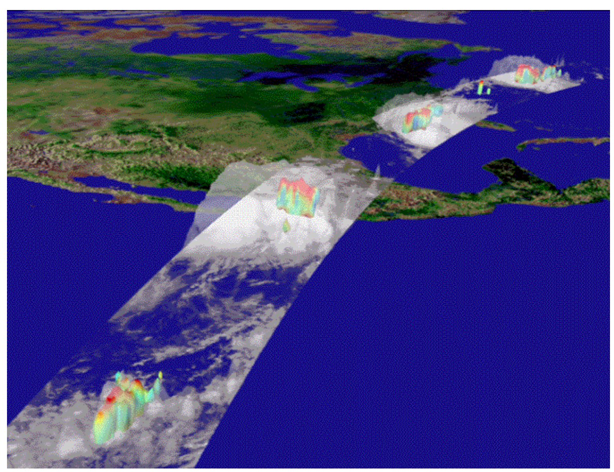


Radar design that enables
Doppler velocity measurements

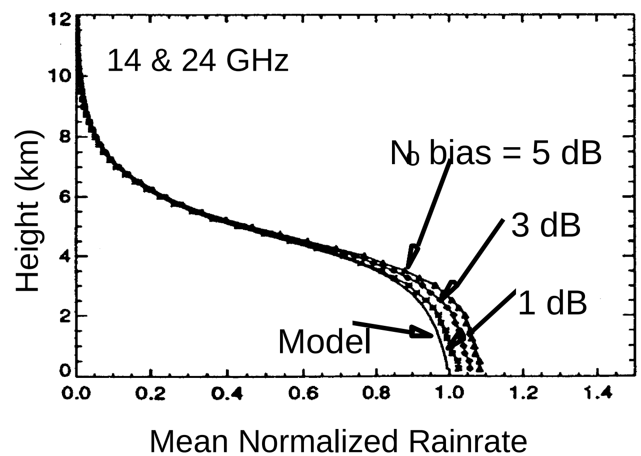
10 mm / hr rain

Vertical Resolution (m	Reflectivity error (%)
10	-0.69
25	-1.70
50	-3.40
100	-6.74
150	-10.00
200	-16.30

Vertical resolution vs.
reflectivity error at 35 GHz



Adaptive scan to enable wide
swath coverage



Dual-frequency to improve
rain retrieval accuracy

4: Retrieval Algorithms

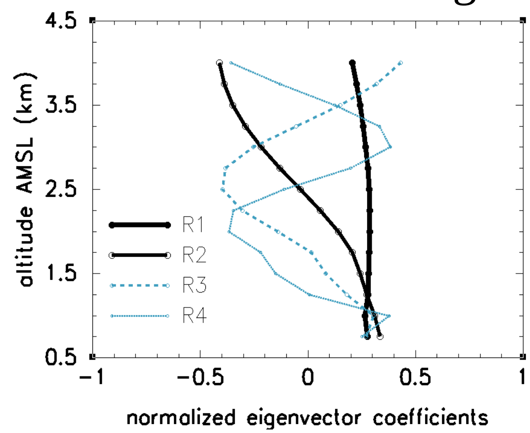
- Main goals:
  - water cycle => surface precipitation (benchmarks: GPI, SSM/I)
  - parametrize convection => latent heating profiles

- Main problems in the estimation process:
  - differentiating between (liquid) rain, hail, graupel, aggregates, snow
  - unknown Drop Size Distribution
  - radar attenuation

- Approach: Develop preliminary assessment of radar algorithms
  - Compile a representative cloud-model simulated storm database and synthesize corresponding “observations”
  - Synthesize 35-GHz “data” from TRMM estimated profiles
  - Analyze dual-frequency wind-profiler data to estimate DSD and synthesize corresponding “observations”
  - Implement various algorithms, apply them to the data and compile performance statistics

Principal Component Analysis of Vertical Hydrometeor Profiles

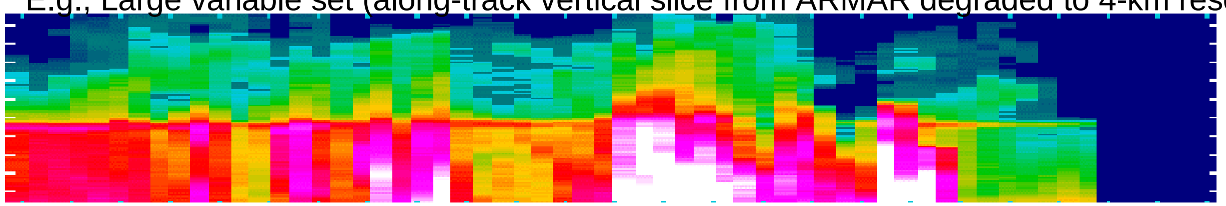
- Haddad et al. Have used Principal Component Analysis (PCA) on TRMM data and modeled outputs to understand vertical hydrometeors and latent heating:
  - First 4 eigenprofiles account for 90% of vertical variability of rain
  - First 2 graupel eigenprofiles account for > 85% of vertical variability of graupel
  - 1st snow eigenprofile accounts for > 90% of vertical variability of snow
  - First 7 latent heating eigenprofiles account for 80% of vertical variability of latent heating



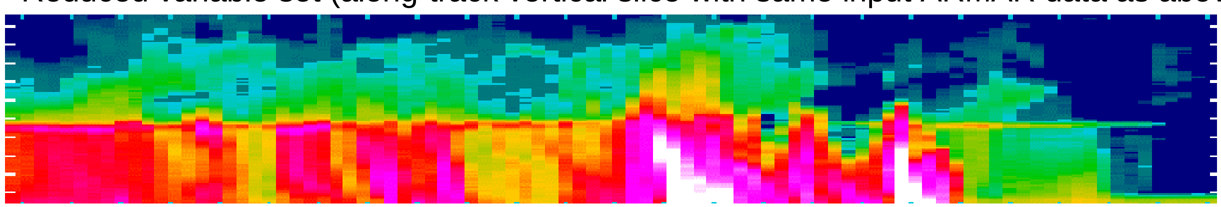
➡ Currently studying optimal way to combine active and passive measurements to “sort out” frozen hydrometeors

- Potential application to wide-swath radar coverage without concerns of surface clutter limitations

E.g., Large variable set (along-track vertical slice from ARMAR degraded to 4-km resolution)



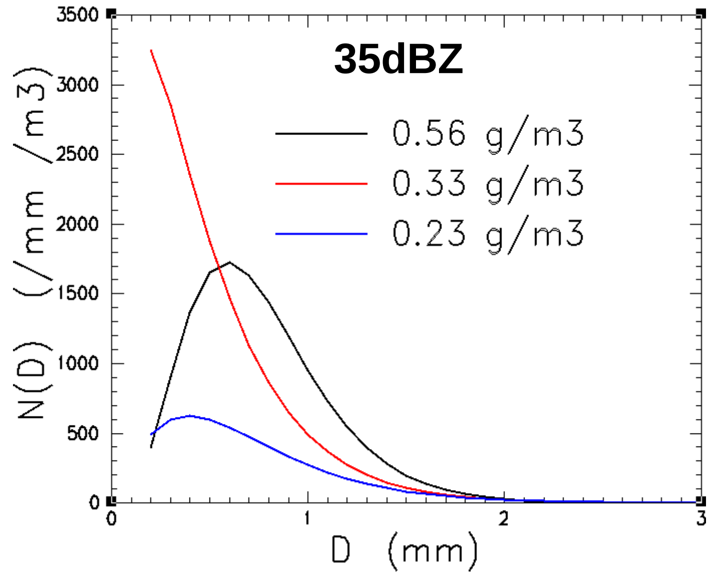
Reduced variable set (along-track vertical slice with same input ARMAR data as above)



Precipitation Retrieval with Radar Algorithm

Learned from TRMM that DSD and non-linearity are the major sources of error:

- DSD is a problem because $Z \sim D^6$ while $M \sim D^3$ (D has unknown distribution)
  - analyze TRMM field campaign data
  - quantify spatial and temporal variability of DSD parameters
  - account for DSD variability when performing the retrievals (to avoid turning a "white" uncertainty into a bias)



- The other non-linearity:

  attenuation $\sim \alpha M^{\beta}$ dB/km, (M in g/m³)

  At 14 GHz, $\beta \sim 1.4$ and $\alpha \sim 0.25$

  At 35 GHz, $\beta \sim 1.3$ and $\alpha \sim 2.5$

and both α and β are DSD-dependent

In example, at 14 GHz, all 3 attenuate ~ 0.2 dB/km, but

at 35 GHz, have 2.6 dB/km, 1.9 dB/km, 1.6 dB/km

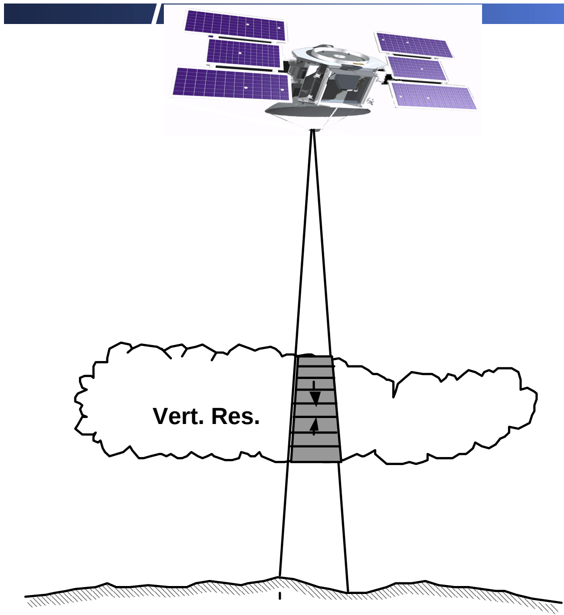
➡ Because we measure (an attenuated) $Z_{average}$, and because $Z \rightarrow M$ is a non-linear relation, must use stochastic approach to estimate $M_{average}$

5: Support Mission and System Concept Tradeoffs

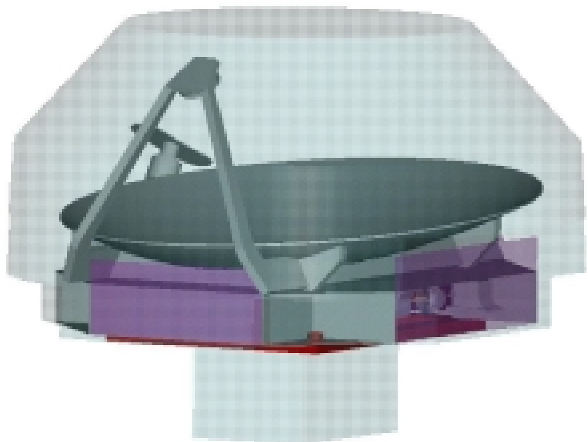
- JPL's Rapid Concurrent Engineering Design Team works closely with GSFC's IMDC will support GPM on:
  - Trade study of various mission architecture concepts
  - Review of the eventual baseline mission concept
  - Develop impact metrics on technology utilization

- Identify newer technologies which have the potential to reduce cost/risk, and/or improve science data return. Examples include:
  - Autonomous station-keeping to reduce operations and maintain precise altitudes or repeat passes
  - Advanced GPS technologies for precision position knowledge
  - Autonomous mission planning technologies for rapid, automated mission planning and coverage assessment

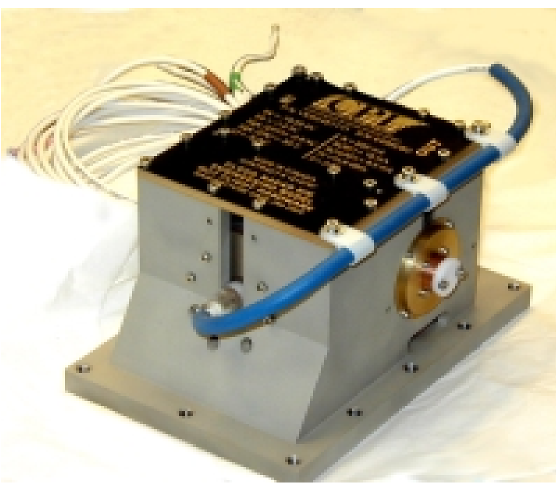
Cloud Profiling Radar for the CloudSat Mission



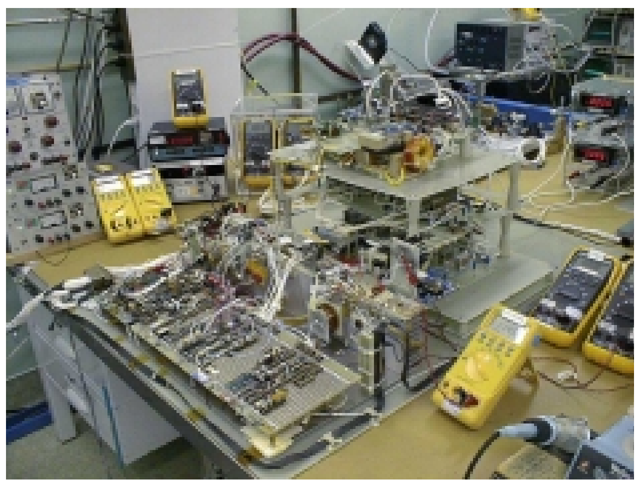
CPR in launch envelope



- CloudSat Mission is a 94-GHz spaceborne cloud radar mission
  - PI: G. Stephens (CSU)
- Partners: CSU, NASA (JPL, GSFC, KSC), CSA, USAF, science team, industries
- 94-GHz radar measures vertical cloud profiles
  - -28 dBZ detection sensitivity
  - 1.4 km horizontal resolution
  - 500 m vertical resolution
- GPM contributions:
  - Inputs to weather/climate models
  - Rain & cloud retrieval algorithms



Extended Interaction Klystron



HV Power Supply Breadboard Model

Collimating Antenna Full-Size Mode